Concrete Curing Meter

simple and reliability monitoring of water loss from a wet surface of fresh concrete

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Publication date:
2002

Document Version
Early version, also known as pre-print

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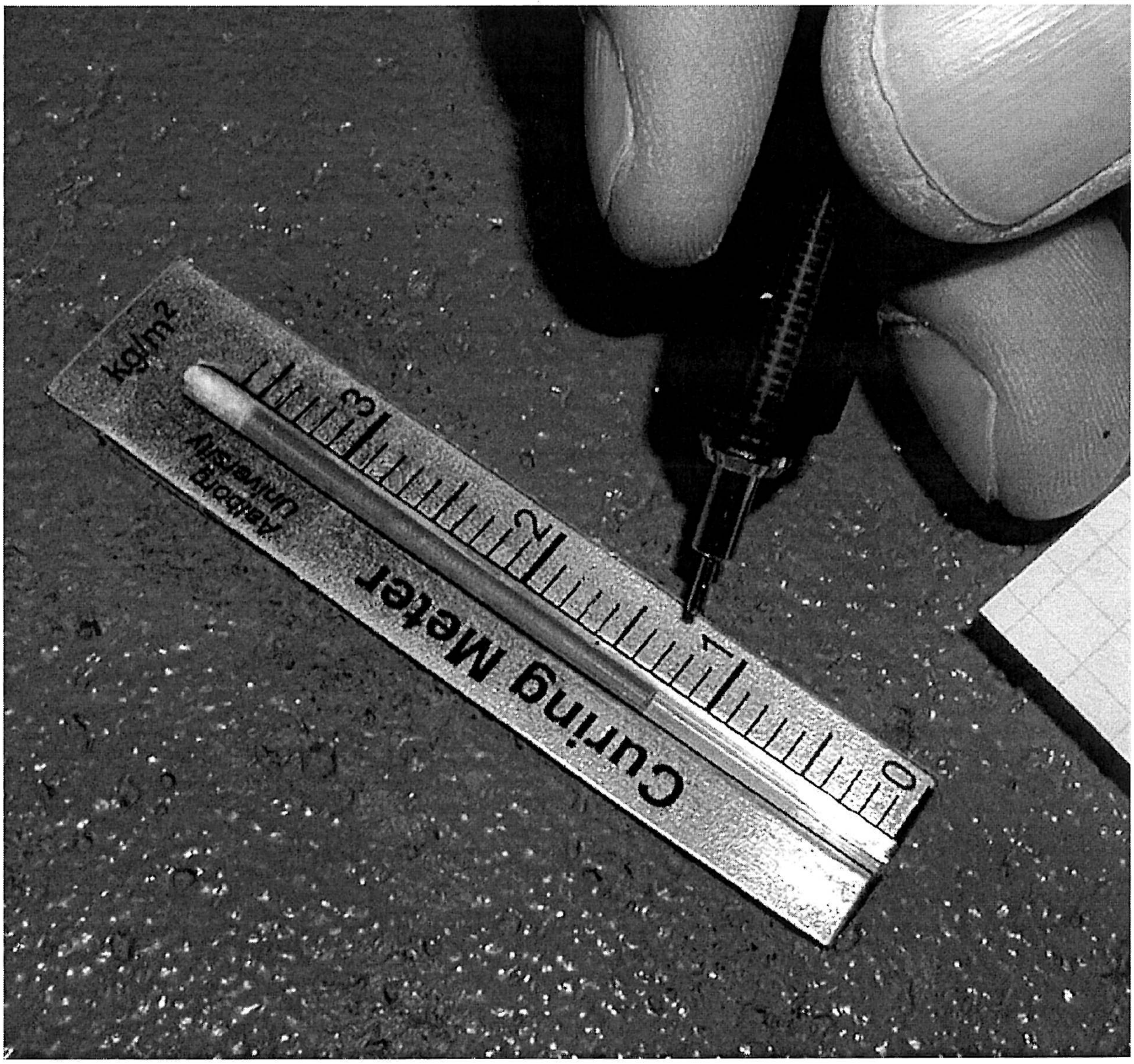

February 2002

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SUMMARY

This report concerns a new method for site measurement of evaporation from concrete surfaces in the early hardening phase. Compared to the methods used today for determination of the desiccation process in the early hardening phase, the Curing Meter permits a simple, safe and accurate determination of the evaporation loss from hardening concrete and thus better possibility for preventing curing problems, including detrimental crack damage due to plastic shrinkage. The Curing Meter technique should be of interest for firms working with casting of concrete structures, concrete pavements, concrete articles or repair of concrete with *Conventional Concrete* and firms working with industrial implementation and utilization of advanced *High-Performance Concrete.* No prior art which damage the novelty of the Curing Meter has been found.

BACKGROUND

Curing Technology concerns adjustment and control of temperature and moisture conditions in hardening structures and elements of concrete. The curing technology comprises e.g. measurement/adjustment/control of the moisture conditions during the early hardening phase of the concrete to achieve an optimal development of properties in the hardening concrete – socalled "moisture curing".

During the latest decades, the development within concrete technology has formed the basis of a new concept: *High-Performance Concrete* [1]. Typically, a *water/cement* ratio (*w/c* ratio) in the range of 0.40-0.60 is used for Conventional Concrete, but today's superplasticisers have made it possible to manufacture relatively fluid concrete with a w/c ratio of 0.20-0.30 when up to 20% silica fume is added. With these extremely dense concretes, concrete strengths of 200-400 MPa can be achieved industrially. In comparison, conventional concrete typically has concrete strengths of 30-50 MPa.

In the theoretical and experimental development of this new concept, Danish concrete research has had a central role. Today several Danish firms are involved in the industrial implementation of *High-Performance Concrete* in targeted special productions.

For *High-Performance Concrete* the requirements for an optimal and controlled moisture curing during hardening are significantly increased: At low *w/c* ratios, even modest losses of water in the early hardening phase may be detrimental to the subsequent hardening and property development of concrete.

It can be expected that the coming years will face a growing need for simple, operational methods to measure, adjust and control the curing conditions of concrete.

The following presentation of the measuring function and potential fields of application of the Curing Meter, therefore, explicitly refers to *Conventional Concrete* and *High-Performance Concrete,* since these two clearly distinct market segments are concerned in connection with the Curing Meter.

PRESENTATION OF PROBLEM

During the first hours after mixing and casting, concrete is plastic and workable. The setting of the concrete – the time where it stiffens and becomes rigid – will normally occur 4-8 hours after adding water and mixing. In the period before and after setting the strength of the concrete is very low, and in this condition the cast concrete is very susceptible to any form of mechanical influence.

If concrete is exposed to heavy desiccation in the period until setting and during setting, detrimental cracking in the concrete surface zone may occur. These cracks – plastic shrinkage cracks – arise because the surface tension of the pore water in menisci builds up critical capillary tensile stresses in the hardening binder phase.

For *Conventional Concrete* crack damages due to plastic shrinkage during the early hardening traditionally present a problem for casting at high temperatures, low relative humidity and high wind velocity. The damages may be particularly critical when the concrete is cast as thin layers, e.g. by shotcreting in connection with repair work. In these cases the reduced layer thickness has the effect that even a limited loss of water by evaporation may cause crack damage due to plastic shrinkage.

According to *American Concrete Institute* ACI 305R-99 [3] actual crack damage can be avoided in mass concrete if the loss of water due to evaporation in the early hardening phase is less than approximately 1 kg/m²h. For thin layers of e.g. shotcrete, however, the permissible evaporation rate is much less than that.

High-Performance Concrete is especially susceptible to desiccation in the early hardening phase, cf. figure 1. This is mostly due to the coincidence of three aspects:

- Due to the low porosity and permeability of fresh high-performance concrete, evaporation loss from the surface zone can only to a limited extent be replaced by water, from the subjacent concrete.
- The high concentration of solid particles in high-performance concrete makes the system "rigid" so that even a modest loss of water will "lock" the particle system, whereupon further loss of water will lead to formation of menisci and capillary tensile stresses in the pore fluid.
- The silica fume added has a typical particle dimension of 0.1μm, which is approximately 100 times less than the average dimension of the cement particles. Therefore the capillary tensile stresses at early desiccation get significantly greater than in conventional concrete.

In *High-Performance Concrete* these detrimental, physical phenomena are further imposed due to the fact that a considerable autogenous shrinkage takes place in the binder phase, which enhances the tendency towards crack formation during hardening.

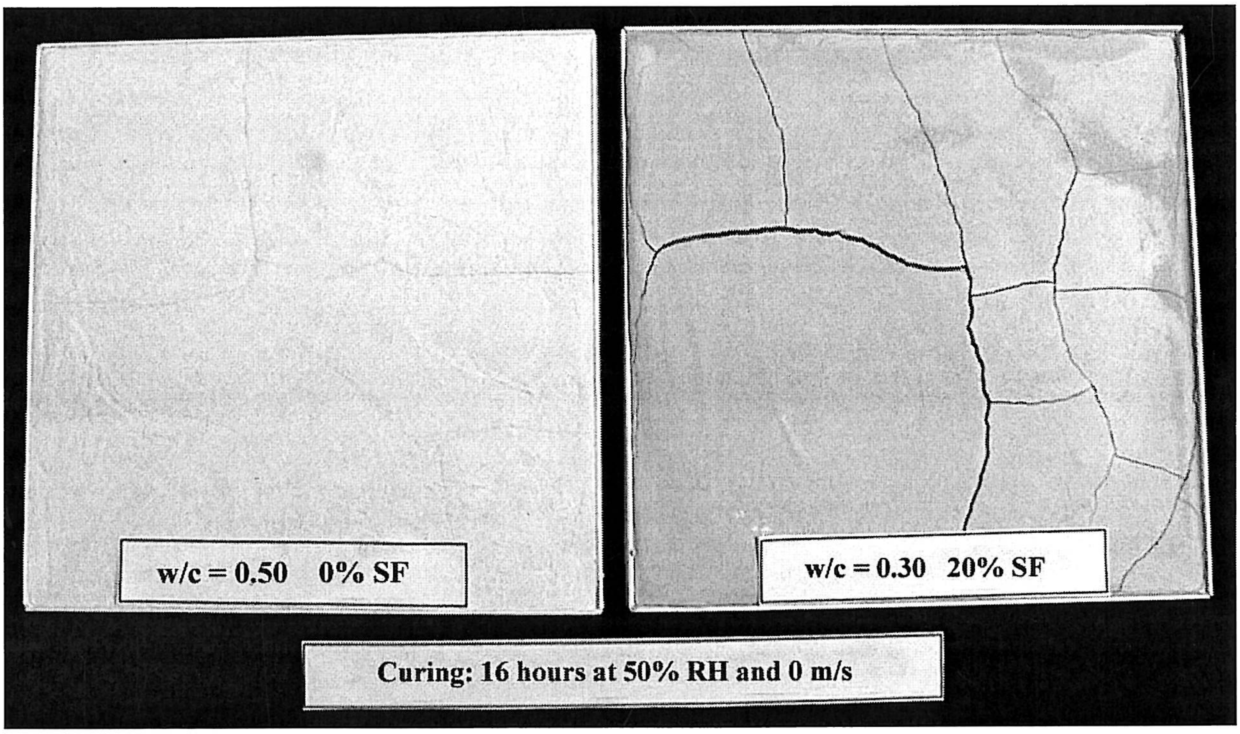


Figure 1. Effect of desiccation in the early hardening phase. To the left a binder phase of Conventional Concrete with a w/c ratio of 0.50 and 0% silica fume. To the right a binder phase of High-Performance Concrete with a w/c ratio 0.30 and with 20% silica fume added. Both specimens are shown after 16 hours of hardening in static air at 20 °C and 50% relative humidity. The specimens shown are 15 x 15 cm and their thickness is 10 mm. The binder phase for Conventional Concrete to the left shows initial cracking, the binder phase for High-Performance Concrete to the right shows serious crack damage due to plastic shrinkage

MEASUREMENT OF EVAPORATION LOSS

The rate of evaporation from a wet concrete surface is governed by a complex interaction of heat capacity and heat development in the subjacent concrete, the temperature and humidity of the ambient air and the wind velocity. After casting the surface temperature of the concrete will adjust in pseudo-psychrometric temperature equilibrium in relation to the ambient air. The rate of evaporation from the wet concrete surface will then be controlled by a number of time-varying parameters such as:

- Air temperature: $\theta_a(t)$
- Relative humidity of the air: $RH(t)$
- Wind velocity at concrete surface: $v(t)$
- Development of heat in the concrete: $Q(t)$

In general, the governing potential difference of the evaporation process is the pressure difference $\Delta p(t)$ between the partial vapour pressure in the ambient air and the partial pressure of saturated vapour at the wet concrete surface. The surface temperature of the concrete – and thus the governing potential difference $\Delta p(t)$ – is significantly influenced by the convectively determined heat and moisture transfer in the boundary layer at the concrete surface, which again depends strongly on the wind velocity of the ambient air, see figure 2.

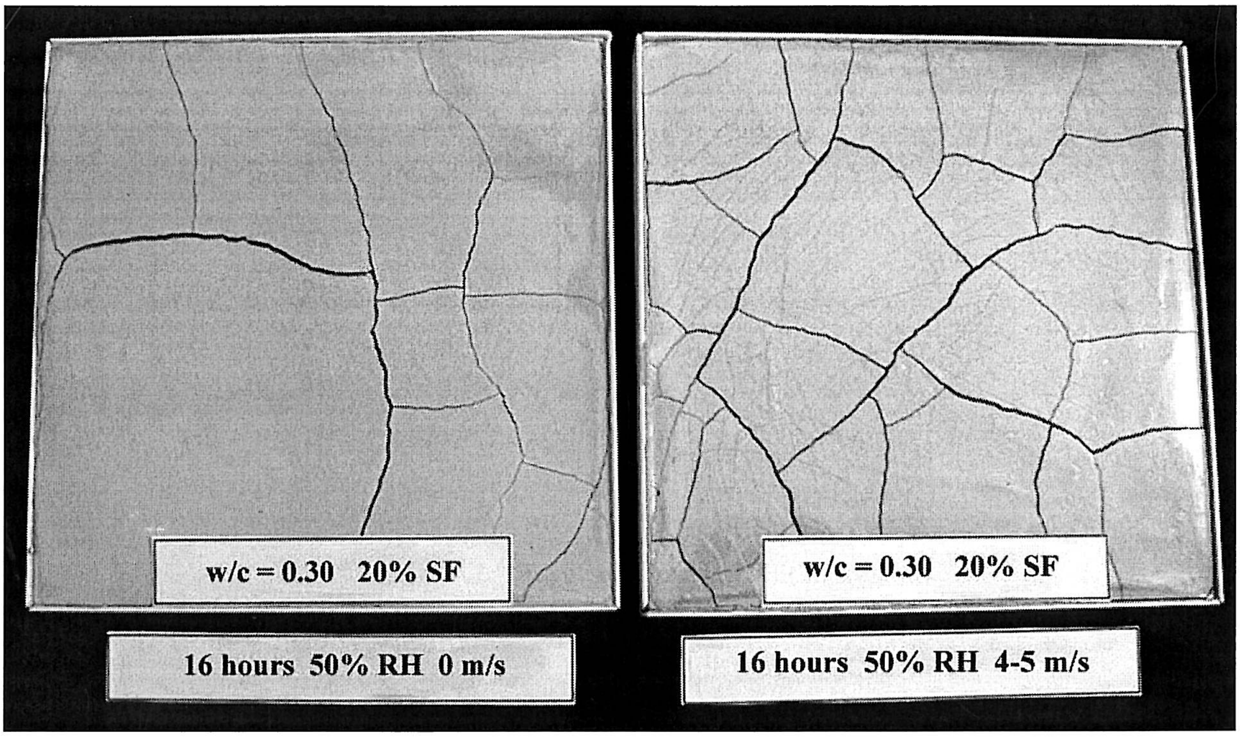


Figure 2. Effect of wind action in the early hardening phase. Both specimens have binder phase of High-Performance concrete with a w/c ratio of 0.30 and with 20% silica fume added. The specimen to the left is shown after 16 hours of hardening in static air at 20 °C and 50% relative humidity. The specimen to the right has been subjected to wind action at 4-5 m/s in the same air climate. The specimens shown are 15 x 15 cm and their thickness is 10 mm. The wind action is seen to have worsened the crack damages due to plastic shrinkage.

Handling of this interaction of a local microclimate, environmental actions and heat development in a subjacent concrete mass is difficult as regards calculation and measurement.

On certain simplified conditions, approximate, simplified calculation expressions to estimate the evaporation rate can be set up for this coupled moisture-heat transport in the boundary layer between the wet concrete and the ambient air. Annex 1 shows an example of a nomogram used today for estimation of the evaporation rate from a wet, hardening concrete surface (*ACI 305R-99*) [3].

If this method for measuring, adjusting or controlling the evaporation loss from green, hardening concrete is applied to building technology, however, it is limited by a number of practical circumstances:

- The parameters used for estimation of the evaporation rate vary in time and place for a given cast concrete structure.
- Estimation of a local evaporation rate requires measurement of at least four quantities, two of which – local wind velocity v and local relative humidity *RH* – should be denoted "transient" numerical quantities.
- It is difficult to register the influence of the heat of hydration on the surface temperature of the concrete at the critical time of setting with ordinarily used measuring equipment.
- The necessary measuring equipment and the necessary experience to estimate the evaporation rate from a wet concrete surface requires a high degree of knowledge on measuring technique.

PROTOTYPES OF CURING METER

The overall idea of the Curing Meter is: to measure the *actual,* integrated evaporation loss from a wet, hardening concrete surface instead of making an approximate *estimation* of instantaneous values of the evaporation rate from the concrete based on time-varying parameters that are difficult to handle.

The *technical specifications* of the Curing Meter are:

- that an evaporation surface with a well-defined area, made from a hydrophilic porous material is ensured intimate thermal contact with the surface of a newly cast concrete, so that the local micro climate over the evaporation surface given by the time-varying evaporation parameters: surface temperature $\theta_s(t)$, air temperature $\theta_a(t)$, relative humidity $RH(t)$ and wind velocity $v(t)$, is identical with the corresponding local micro climate over the surrounding concrete surface,
- that the pseudo-psychrometric temperature drop $\Delta\theta_s(t)$ in relation to the ambient air temperature $\theta_a(t)$ is the same for the evaporation surface of the Curing Meter as for the surface of the surrounding concrete,
- that water is added to the evaporation surface from an embedded capillary tube designed in such a way that the evaporated quantity of water $w(t)$ (kg/m^2) from the concrete surface can be read on a calibrated scale at the capillary tube.

With regard to *methods* the following features characterize the Curing Meter:

- it is a low-price, mass-producible disposable meter, which after simple stripping can be activated and brought to function by indentation in a newly cast surface of concrete,
- measurement of the integrated evaporation loss from a wet, hardening concrete surface can be made quickly and simple at the building site by personnel without specific technical knowledge on how to measure temperature, wind velocity and relative humidity.
- the measurement makes it possible to prescribe well-defined and controllable requirements for moisture curing in work specifications for the concrete work,
- in a simple and low-price manner it is possible by measurement to document compliance of requirements in work descriptions for the finishing moisture treatment of the concrete
- the measurement replaces a complicated and expensive technical evaluation of the evaporation loss from a wet, hardening concrete surface and is at the same time assumed to render much better safety and accuracy.

This measuring concept has been tested with different prototypes of the Curing Meter. Examples of manufactured and tested prototypes of the Curing Meter are shown in figure 3.A and figure 3.B. The measuring system consists of a circular evaporation surface of gypsum with a *water/gypsum* ratio of 0.60. An embedded capillary tube with inner aperture of Ø 0.9 mm is in hydraulic contact with the evaporation surface.

The evaporation surface with capillary tubes is either placed on top of a 0.5 x 15 x 65 mm base plate of aluminium (fig. 3.A) or inserted in a 1.5 mm acrylic plate of the same dimension (fig. 3.B).

The capillary tube contains water to which colour is added. During measuring the Curing Meter is brought into close thermal contact with the wet sublayer so that evaporation surface and sublayer have the same temperature. The scale on the base plate has been calibrated so that the evaporation loss from the concrete can be read directly in kg/m².

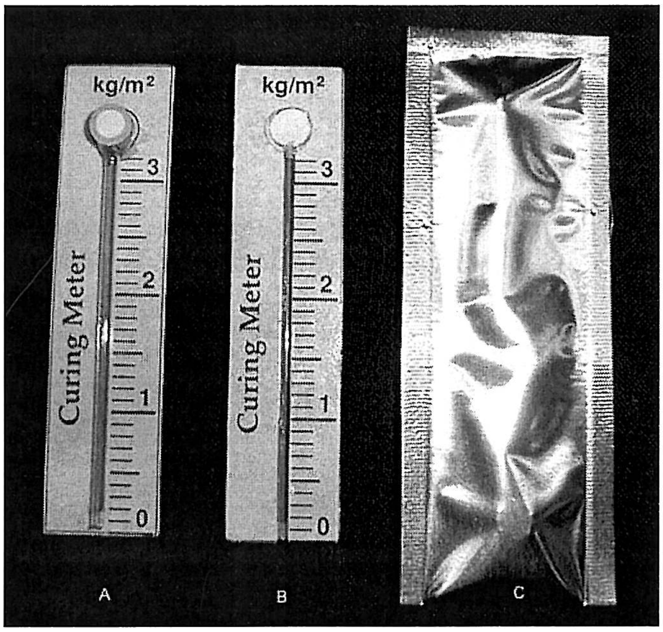


Figure 3. Prototype of the Curing Meter used for testing the suggested technique to measure the evaporation loss from a wet, hardening concrete surface. Gypsum with a water/gypsum ratio of 0.60 has been used as evaporation surface. A: a Curing Meter mounted on a 0.5 mm thick aluminium plate. B: a sensor inserted in a 1.5 mm thick acrylic plate mounted on an aluminium plate. C: a sensor sealed in a diffusion-proof foil for storage before use. The prototypes of Curing Meters are shown in their full size: 15 x 65 mm.

In case of industrial mass production of the Curing Meter, e.g. the following two designs would be possible:

1) The Curing Meter is injection moulded in a hard type of plastic with low water absorption, e.g. Polystyrene or ABS. The capillary tube can either be a separate glass tube mounted in a groove or it can be a cast opening in the base plate itself. The evaporation surface is formed in a circular gypsum-filled cavity at the end of the capillary tube. The total thickness of the base plate will be 1.6-1.8 mm. The final appearance of the Curing Meter will be approximately as the prototype shown in figure 3.B. Also the evaporation unit could be made of a small porous, ceramic brick.

2) The base plate of the Curing Meter is moulded and punched in one operation from a 0.2-0.3 mm aluminium plate. During moulding an approximately 1.4 mm deep groove for the capillary tube is formed together with a well-defined cavity of the same depth for the gypsum-filled evaporation surface. The thermal properties of this design will be better than those shown under 1) due to the high thermal diffusivity of aluminium.

It is possible to adapt the sensitivity and measuring range of the Curing Meter to a large number of different applications through the choice of diameter ratio between the capillary tube and the evaporation surface.

For application in practice, the end of the capillary tube may protrude from the base plate and be sealed. After vacuum filling of capillary tube and evaporation surface, the base plate is enclosed in a saturated, alga-proof and diffusion proof seal as shown in figure 3.C.

For measuring purposes the sealing is broken, the end of the capillary tube is broken off, and the Curing Meter is pressed into the concrete surface.

Another possible procedure for activation of a Curing Meter is to fill it with water at start of measurement. This can be done in a controlled way by partially dipping the Curing Meter in water. The evaporation surface should be held above the water surface to allow complete and automatic filling by capillary suction. The filling may take between a few seconds and a minute depending on the permeability of the evaporation surface. After wiping the Curing Meter is ready for measurement.

Figure 4 show an operational Curing Meter for measurement of water loss from floor toppings of High-Performance Concrete. Also shown is a test set-up for calibration of the Curing Meter.

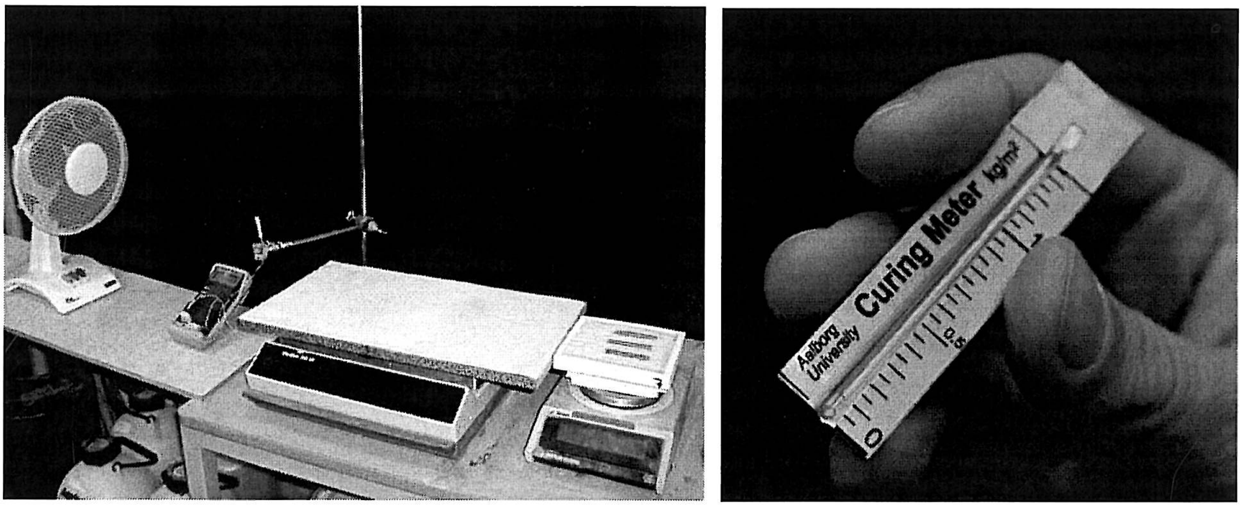


Figure 4: Left: Test setup used for calibration of the Curing Meters. The Curing Meters are placed on a wet fiber mat and exposed to a controlled climate. The graduation on the Curing Meter is constructed based on Curing Meter readings and weight loss from the fiber mat. The boundary layer build-up takes place on a separate, saturated fiber mat on the wind side, outside the local Curing Meter exposure zone. Right: Curing Meter with a calibrated graduation. The sensitivity of the Curing Meter can be modified by changing the size of the evaporation surface or the capillary tube.

TESTING OF PROTOTYPES

A number of measurements have been made with different prototypes to test and demonstrate the principle of the Curing Meter. During measuring Curing Meter sensors were mounted on test specimens with a well-defined evaporation area. The test specimens were placed on a digital scale with 0.001 g solution. The actual evaporation loss from the test specimen was thus recorded in kg/m² and compared with the reading of the Curing Meter. During the tests, the wind velocity v (m/s) and RH (%) above the test surface were varied.

During the tests the temperature of the ambient air θ_a, the relative humidity RH, the wind velocity v and the temperature of the wet concrete surface were recorded. Figure 5 shows an example, where the specimen has been subjected to a complex desiccation process. Figure 5.1 shows changes of the relative humidity RH and figure 5.2 shows the changes in wind velocity v made during the test. As seen from figure 5.3, the evaporation rate is drastically influenced by these changes of boundary conditions. The integrated, measured evaporation loss from the test specimen during measuring is shown in figure 5.4.

After 120 minutes and right after the covered period, an evaporation rate of 0.70 kg/m²h is measured. At this time the temperature of the specimen corresponds to the air temperature, i.e. approximately 22°C; the relative humidity is approximately 35% and the wind velocity approximately 4.5 m/s (approx. 16 km/h). Using these boundary conditions it is possible, as shown by (A) in the ACI 305R-99 nomogram (annex 1) [3], to estimate by calculation the evaporation rate of approx. 0.7 kg/m²h, which is in close accordance with the measured value. As seen from figure 5.3, continuous measurement and nomogram based evaluation of the desiccation action as shown in annex 1, is too complex and time-consuming under these circumstances, since four time-dependent parameters are included in each determination of the evaporation rate. Furthermore, in practice the governing curing parameter is the integrated evaporation loss corresponding to figure 5.4.

Figure 5: Example of measuring programme for Curing Meter test

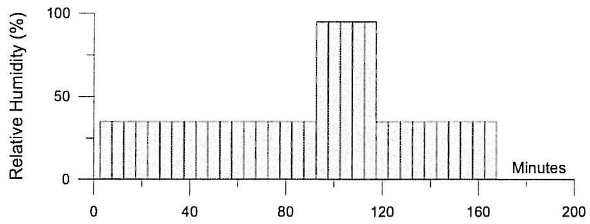


Figure 5.1: Relative humidity RH over test specimen during the early hardening. RH was approximately 35% apart from a period with cover during which RH was 90-100%.

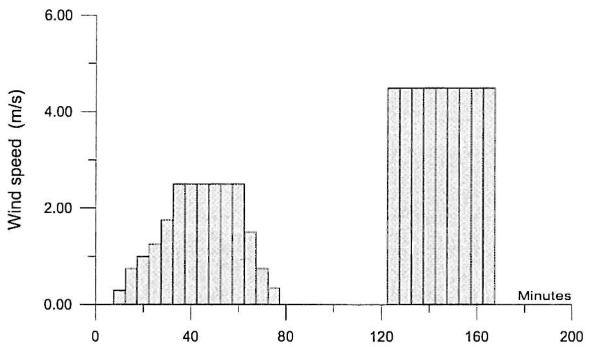


Figure 5.2: The figure shows the approximate wind velocity at the surface of the test specimen during the early hardening. As seen the wind velocity has been kept constant as well as increasing or decreasing, respectively, during measuring. Maximum wind velocity 4-5 m/s; for some periods of time, the specimen has been surrounded by static air.

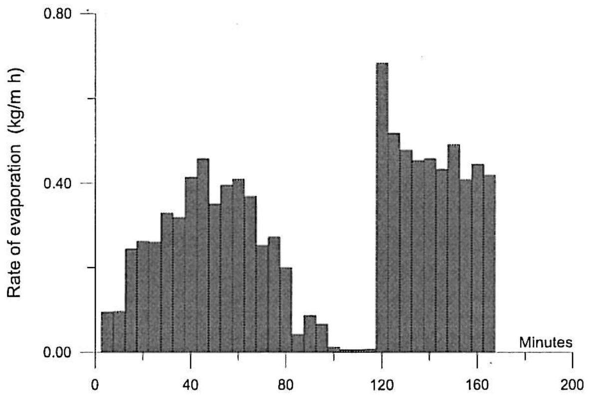


Figure 5.3: Measured evaporation rate from the specimen during the measuring period. The evaporation rate varied from approx. 0 kg/m²h in the cover period to approx. 0.70 kg/m²h in the period with maximum wind velocity. Note that the maximum evaporation rate occurs right after the cover period. At this time the temperature of the specimen has risen to a value close to the air temperature in the room. As the psychrometric cooling gradually reduces the temperature in the specimen, the evaporation rate decreases once more.

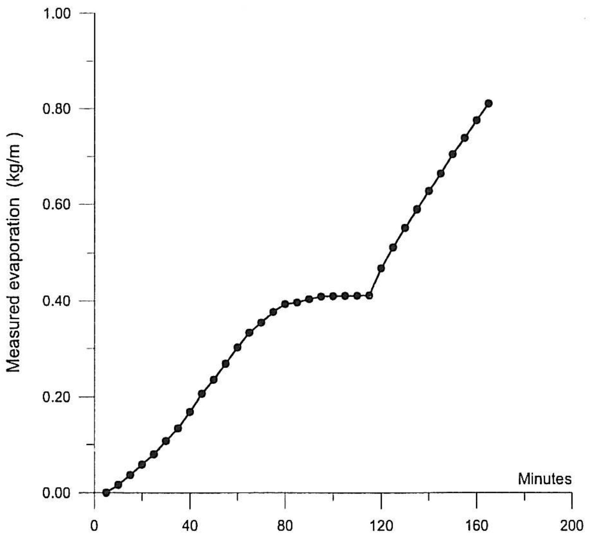


Figure 5.4: The measured, integrated evaporation loss from the specimen during measuring. The curve represents the time integral of the evaporation rate shown in figure 5.3. During testing initial crack indication could be seen on the surface after 100-120 minutes of exposure, and after 140-150 minutes there were distinct, open cracks on the surface. This supports the theory that the risk of formation oj plastic shrinkage is highly dependent on the thickness of the specimen.

On the other hand, the tests of the Curing Meter have demonstrated that even for rather complicated changes of boundary conditions the Curing Meter technique can be applied in a simple manner to determine the integrated evaporation loss very accurately. For the actual desiccation test, the Curing Meter readings have been compared with the measured evaporation loss by weighing, see figure 6.

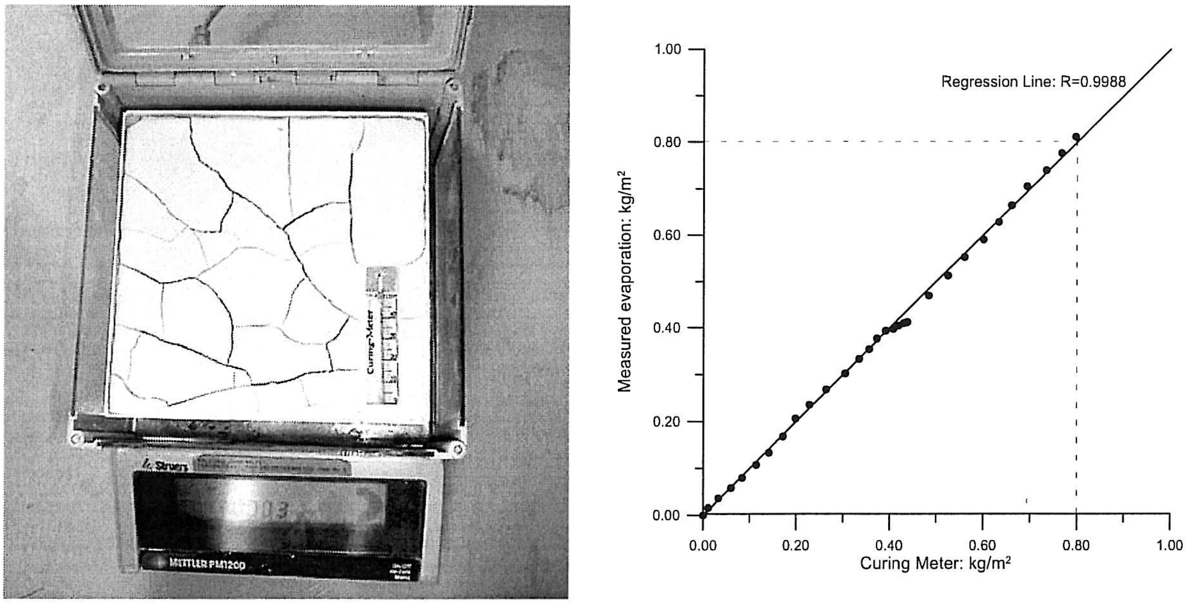


Figure 6: Left: Test setup used for testing Curing Meter prototypes. The tested binder phases are cast in a 15 x 15 x 1 cm form. After casting the Curing Meter is mounted in the binder phase and the sample is placed on a scale with 0.001 g solution. Right: Example of testing of the Curing Meter during exposure conditions given in figure 5. The investigated specimen is binder phase with a w/c ratio of 0.30 and 20% silica fume added. The figure shows the measured evaporation loss in kg/m^2 compared with the values read from a calibrated Curing Meter. The Curing Meter used was a prototype with rectangular evaporation surface, a design with a number of production-related benefits.

Effect of gravity

Figure 7 shows the effect of gravity on the Curing Meter operation. The orientation of the Curing meter relative to gravity has been varied in order to examine this effect. As seen from the figure there does not seem to be any significant influence of gravity with the tested Curing Meter design. A coarser capillar tube might induce an influence of gravity, however, this is not relevant since it would also make the Curing Meter shock sensitive.

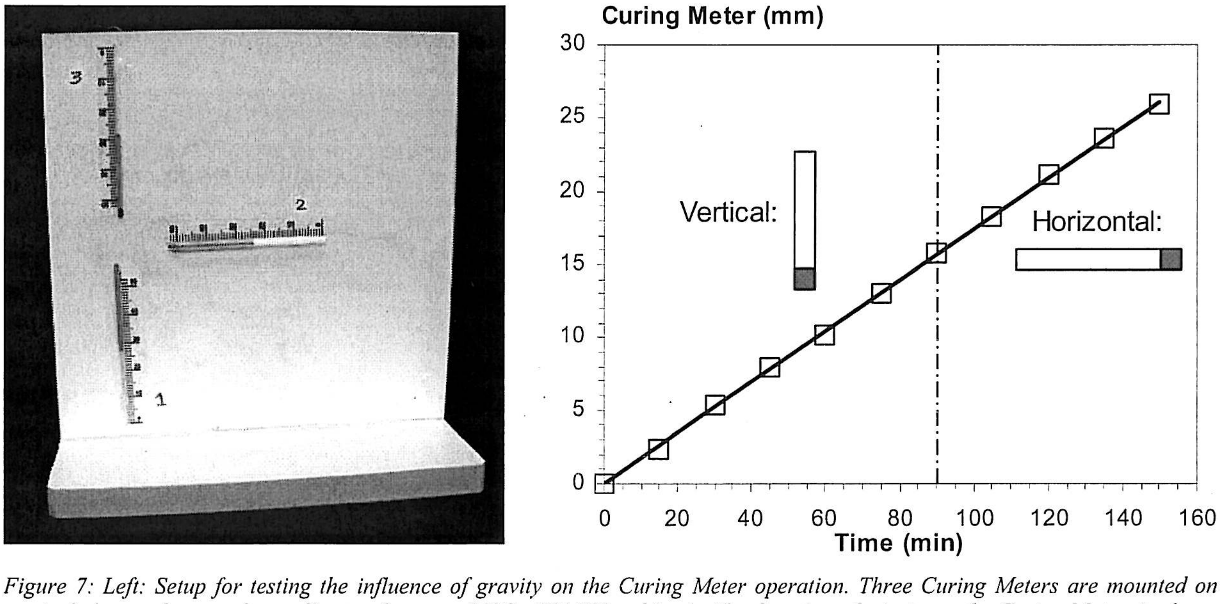
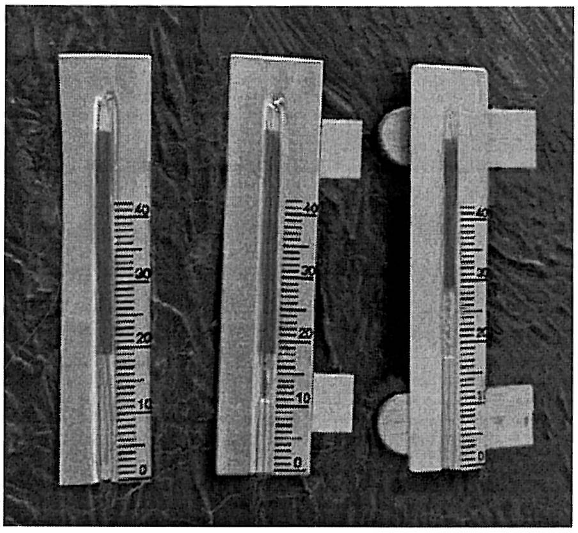


Figure 7: Left: Setup for testing the influence of gravity on the Curing Meter operation. Three Curing Meters are mounted on a vertical plate and exposed to a climate of approx. 20°C, 40% RH and 2 m/s. The direction of gravity on the Curing Meters is changed by rotating the plate 90° clockwise. Right: Example of measurements with the top Curing Meter in the left figure. The orientation of the Curing Meter has been changed at 90 minutes. The graph shows no notable influence of gravity.

Effect of thermal contact

Figure 8 shows the effect of thermal contact with the concrete surface on the Curing Meter operation. When the Curing Meter is fully thermally detached from the concrete surface the Curing Meter reading is significantly increased. This is caused by the higher temperature of the Curing Meter, i.e. the psychrometric cooling of the surrounding concrete is not transferred to the evaporation surface of the Curing Meter. However, due to the high thermal diffusivity of aluminium even a slight contact between the Curing Meter and the concrete surface is enough to ensure correct operation of the Curing Meter reading.



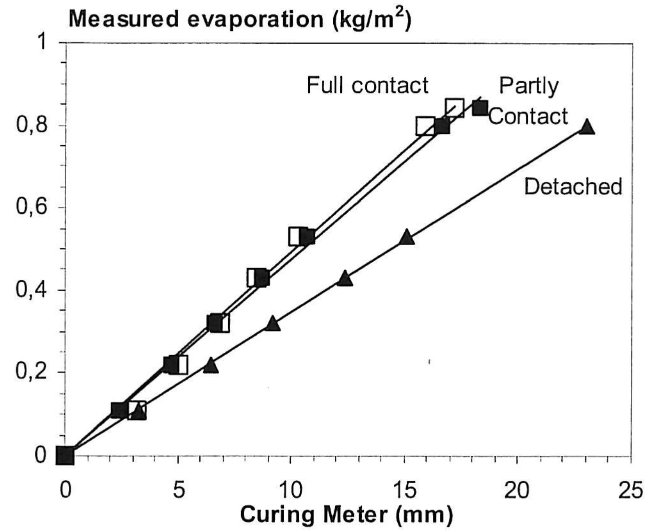


Figure 8: Left: Test of the influence of thermal contact on the Curing Meter operation. The Curing Meters are placed on cement paste exposed to a climate of approx. 21°C, 45% RH and 2 m/s. The left Curing Meter is fully indented in the paste surface, the mittle Curing Meter has paste contact only along one edge, and the right Curing Meter is fully detached from the paste. Right: Example of measurements where the thermal contact has been varied. Only at full detachment the operation of the Curing Meter is obstructed.

Effect of shielding of concrete surface

The base plate of the Curing Meter shields the concrete surface. This locally prevents evaporation from the concrete surface and alters the thermal properties in this area. This may consequently influence the Curing Meter operation. Versions of the Curing Meter with parts of the aluminium base plate removed were tested to examine the magnitude of this influence. In extreme all aluminium but a small rim around the evaporation surface was removed. These experiments did not show any influence from the aluminium base plate in the tested size, approx. 15 x 65 mm.

Effect of capillary tube evaporation

Water loss from the Curing Meter will occur both from the evaporation surface and through the open end of the capillary tube. This water loss is undesirable since it is not under climate control like the water loss from the evaporation surface. However, tests show that water loss from the open end of the capillary tube can be neglected, see figure 9. A reason for this is that the evaporation surface is much larger than the capillary tube opening – more than 10 times. Another factor which significantly limits this water loss is diffusion resistance in the capillary tube. As the meniscus moves away from the open end of the capillary tube a very significant decrease in the evaporation from the open end is observed. In figure 9 the observed drift during 1 hour with the evaporation surface sealed is approx. 1 mm. A further 5 days exposure to a climate of approx. 20°C, 30% RH and still air only leads to a Curing Meter drift of 13 mm.

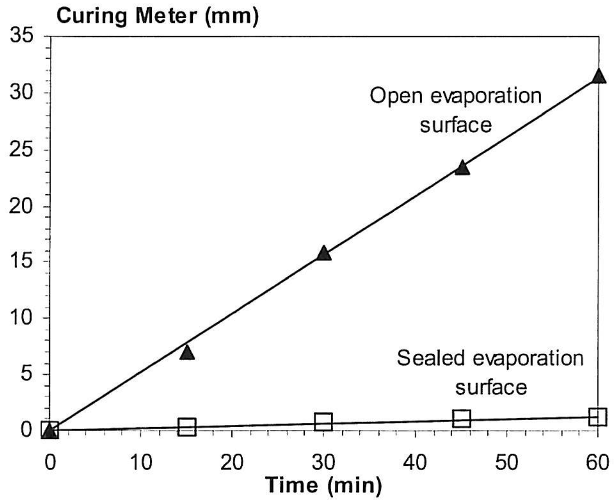
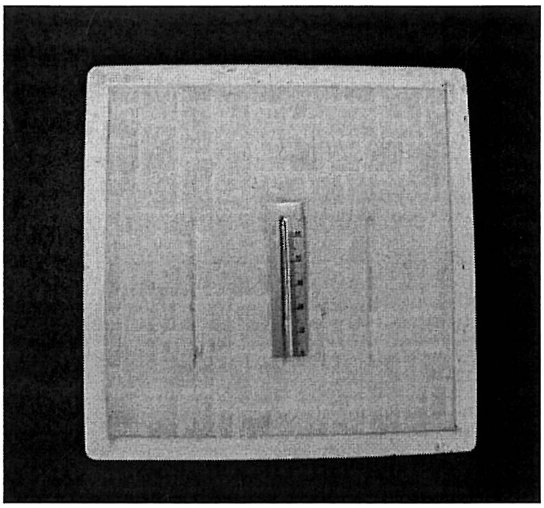


Figure 9: Test of the influence of water loss from the open end of the capillary tube. The Curing Meters are placed on on a dry fiber mat as shown in Figure 10 to the right. The exposure climate is approx. 20°C, 30% RH and 2 m/s.

Effect of temperature

The operation of the Curing Meter has been tested at two temperature levels, approximately 21°C and 33°C. As shown in figure 10 the calibration of the Curing Meter seems to be slightly influenced by the temperature. However, this slight influence may, potentially, be an artefact from the test setup rather than from the Curing Meter measurement itself. Especially due to the wind action there will be a distinct evaporation profile across the sample. The shape of this evaporation profile will change with temperature. Whereas the Curing Meter readings are controlled by the microclimate at the center of the test sample, the measured evaporation is an average of the evaporation across the sample; The temperature change may have induced a change in the relation between total evaporation from the sample and evaporation on the center of the sample. The evaporation profile was clearly identified by a subsequent test where the Curing Meter was placed acentric on the sample; In that case the wind direction had a significant effect on the Curing Meter readings caused by the boundary conditions.



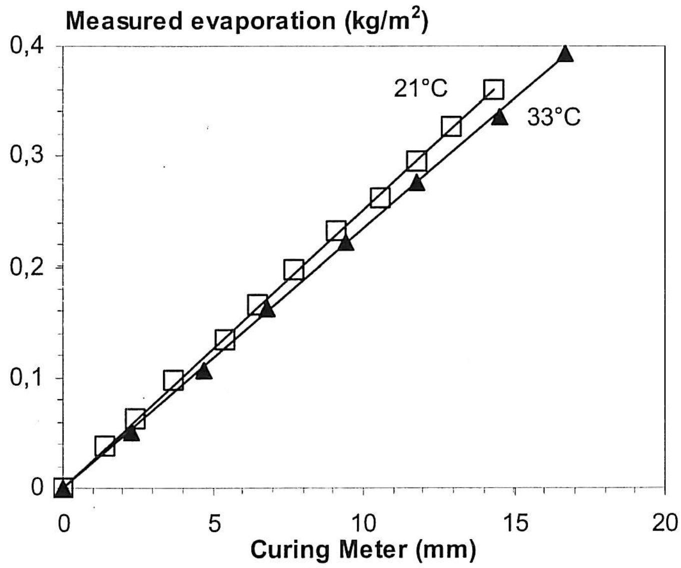


Figure 10: Test of the influence of temperature on the Curing Meter operation. Left: The Curing Meter is placed on a water saturated fiber mat. Right: Example of measurements at two different climate conditions: a) approx. 21°C, 40% RH and 2 m/s, and b) approx. 33°C, 20% RH and 2 m/s. The slope of the two desiccation courses deviate by 8%. This small difference may, potentially, be due to the test setup rather than the Curing Meter operation as discussed in the text.

Effect of evaporation surface

Evaporation surfaces made of different materials and with different pore sizes were tested. This was done by measuring the evaporation from discs, Ø 40 mm, in hydraulic contact with a reservoir of free water, see figure 11. The materials tested were gypsum, fresh cement paste and porous glass (Schott Duran glass filter discs, sintered, surface untreated). The porous glass was tested in four different pore sizes: approx. 15, 30, 70 and 130 µm. Also the results were compared with the water-loss from a free water surface. The results did not indicate an influence from the evaporation surface.

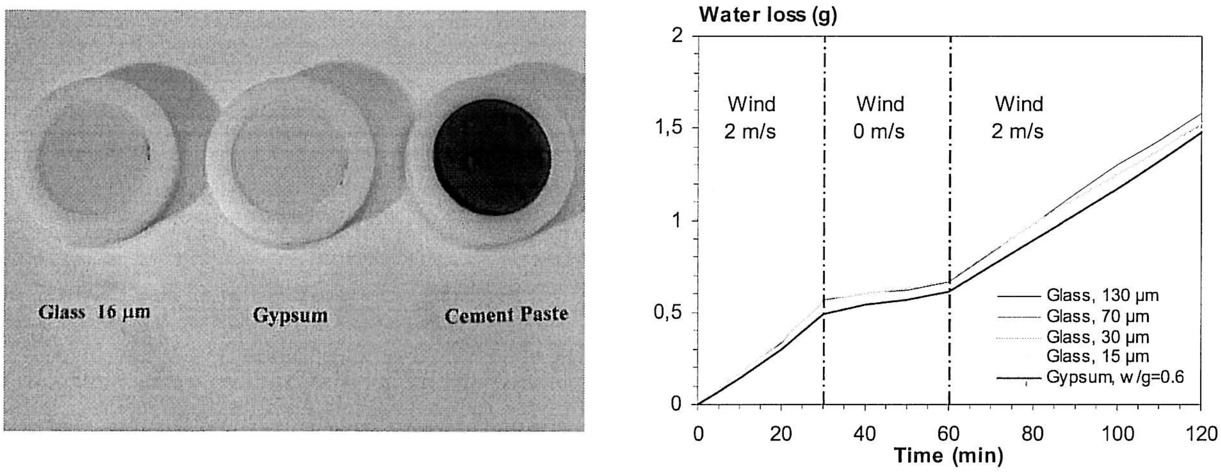


Figure 11: Influence of material for the evaporation surface on the Curing Meter operation. Left: Examples of specimens. Water is supplied to the surface from a reservoir under the material. Right: Example of a test at approx. 22°C, 30% RH and different wind velocities.

APPLICATION OF THE CURING METER

An electronic search has been made in patent and literature databases by a patent agency and investigations have been made at vendors of related measuring equipment for the concrete field. This search has not revealed any prior art damaging the novelty of the Curing Meter. Compared to the methods used today for monitoring of the desiccation process in the early hardening phase, the Curing Meter permits a simple, safe and more accurate determination of the evaporation loss from hardening concrete. This permits systematic safeguarding against curing problems, including detrimental crack damage due to plastic shrinkage.

Especially within two concrete areas there should be interest in the Curing Meter technology:

1) Casting of concrete structures, concrete pavements, concrete tubes, concrete articles or repair of concrete with *Conventional Concrete.* In these cases the Curing Meter can be applied for site measuring, adjustment or control of the desiccation action to which concrete is exposed in the early hardening phase. For these kinds of concrete work the code of practice stipulates a number of specific requirements for moisture curing that can be documented only with difficulty. An example of such requirements is given in the Danish code DS 482 [4], which lists limits for the total permissible evaporation. In connection with socalled *Hot Weather Concreting* [3] there is a particular need for methods for measuring, adjustment and control of desiccation action on the site.

2) Industrial implementation and utilization of advanced *High-Performance Concrete.* The binder phase in today's high-performance concretes is particularly sensitive to desiccation action. In curing technology this means that the requirements for optimal and controlled moisture curing are significantly increased for manufacture of these kinds of products. In a simple manner the Curing Meter permits fulfilment of these stricter requirements for moisture curing. In recent years the market for special products made from high-performance concrete has been on the upgrade.

The producer or distributor of the Curing Meter may take advantage both from the direct economic possibilities or consider the indirect benefit as a part of a marketing policy. The following rough estimate evaluates the direct, upper market potential for the Curing Meter.

In Denmark approx. 1 million m^3 concrete is manufactured every year within the areas: Site-cast covers, repair work and civil engineering structures. These are the areas directly relevant for the application of the Curing Meter. Application of one Curing Meter per 100 m^3 of concrete will result in an annual consumption in Denmark of 10,000 Curing Meters. Denmark's population constitutes approximately 1/500 of the industrialized world. A rough estimate of the world potential of the Curing Meter will thus be approximately 5 million per year.

Utilization of this potential will depend on a great number of factors. A targeted marketing will probably be necessary for efficiently working up the market for the Curing Meter. A supplementary element in this will be to have the Curing Meter measuring technique implemented in codes like ASTM and ACI. Also exposure of the Curing Meter through scientific papers and conferences will promote this. Surely there is a market need for the Curing Meter. Concrete contractors, ready-mixed concrete producers and concrete designers are caught up in lawsuits regarding why concrete has cracked. Both the part who defines requirements on concrete as well as the part who has to satisfy the requirements needs an operational control instrument. The Curing Meter fills in this lack.

REFERENCES

[1] P.-C. Aïtcin, High-Performance Concrete, E & FN SPON, London, 1998

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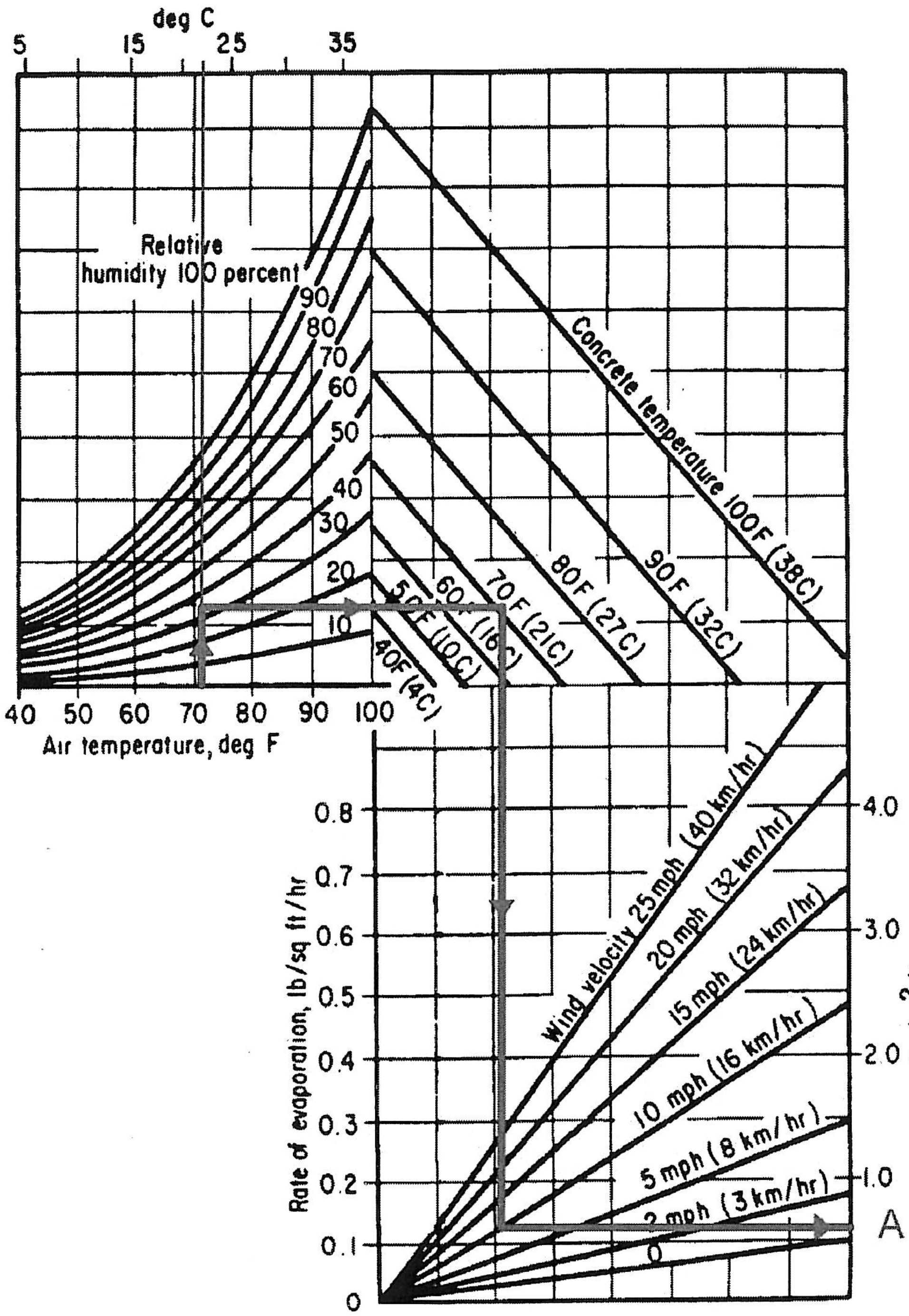
[3] Manual of Concrete Practice, ACI 305R-99, Hot Weather Concreting, American Concrete Institute, Farmington Hills, Michigan, 2001

[4] Execution of Concrete Structures (in Danish), Danish Code, DS 482, 1999

Annex 1

Nomogram: ACI 305R-91
Hot Weather Concreting



Annex 1: Effect of concrete temperature, air temperature, relative humidity and wind velocity on the rate of evaporation from a wet concrete surface. Today this nomogram is recommended by ACI Committee 305 [2] for estimation of desiccation action of concrete in the early hardening phase. The figure shows the estimated rate of evaporation from the Curing Meter test: Concrete temperature and air temperature 22°C, relative humidity RH 35% and wind velocity 4.5 m/s (~16 km/h). The estimated rate of evaporation of approx. 0.7 kg/m²h is in close agreement with the value measured by the Curing Meter.